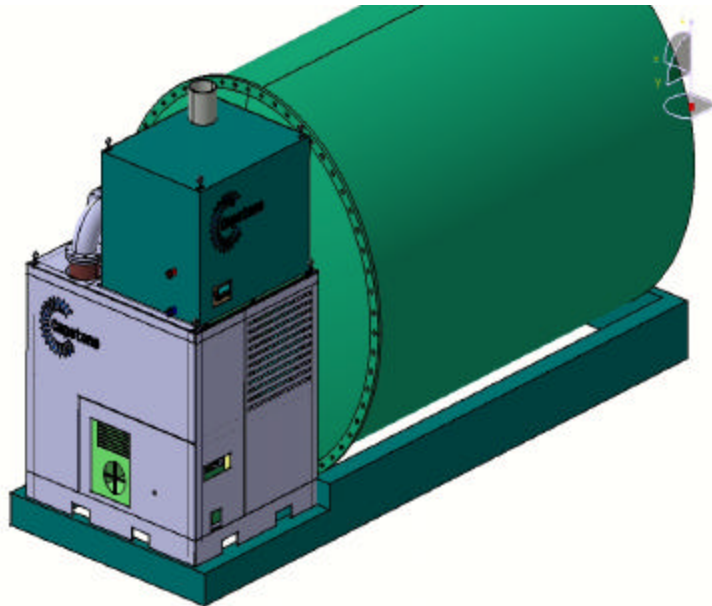


MicroTurbines & Fuel Cell Hybrid Power Systems (HPS)



Bill Treece
Capstone Turbine Corporation

April 17, 2002



MicroTurbines & Fuel Cell Hybrid Power Systems (HPS)

Some microturbine HPS integration issues:

- Microturbine control without fuel flow regulation
- Microturbine must respond to fuel cell air flow demand
- Air flow range required by fuel cell
- Avoid contamination of fuel cell air supply
- Air flow at altitude & ambient temperature extremes
- Controlled: starting, warm-up & cool down of the fuel cell

MicroTurbines & Fuel Cell Hybrid Power Systems (HPS)

Microturbine modifications required for HPS:

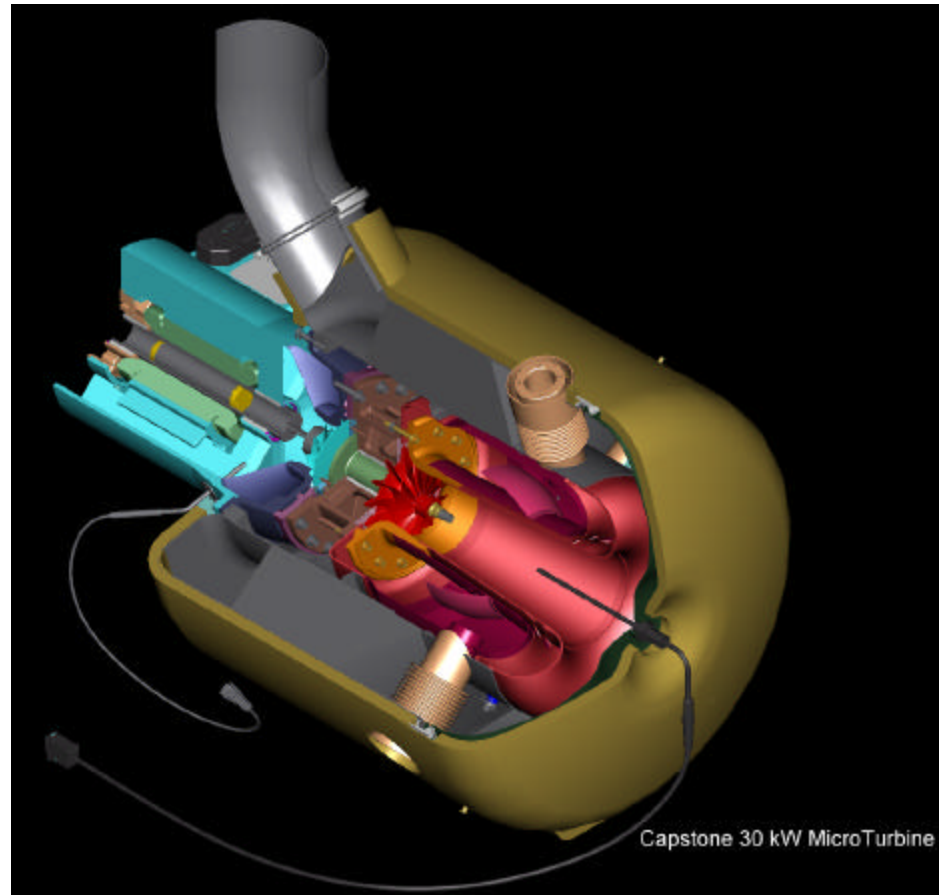
- Air out to fuel cell
- Hot gas return from fuel cell
- Control logic & software
- Fuel cell to microturbine communication
- Packaging, interface resolution, piping & valves

MicroTurbines & Fuel Cell Hybrid Power Systems (HPS)

Microturbine desirable features for HPS:

- Variable speed (air flow demand)
- Power electronics (motor/generator, input/output frequency –vs- speed, control)
- Single shaft (control [cost] \$/kW)
- Air bearings (long life & no contamination)
- Compressor surge margin (transient response)
- Maximum commonality with production (\$/kW)

MicroTurbines & Fuel Cell Hybrid Power Systems (HPS)



Capstone 30kW Microturbine

April 17, 2002



MicroTurbines & Fuel Cell Hybrid Power Systems (HPS)

Capstone MicroTurbine Experience:

- More than 2,000 microturbines produced
- Exceed 1.3 million field operating hours
- High time microturbine over 27,000 hours
- High cycle microturbine over 14,000 cycles
- 3,000+ hours operation in HPS @ fuel cell energy



April 17, 2002



MicroTurbines & Fuel Cell Hybrid Power Systems (HPS)

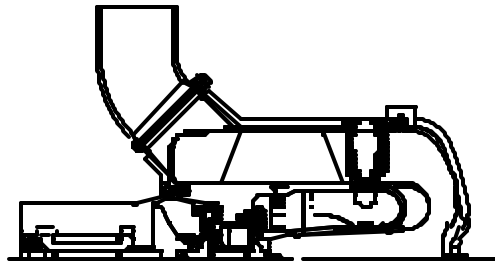
Capstone MicroTurbine Product Family:

- 30kW @ 0.7pps & 3.6p/p---production 1998
 - 60kW @ 1.1pps & 4.8p/p---production 2000
 - 200kW @ 2.8pps & 4.1p/p---production 2004
- [All have the desirable HPS features!]

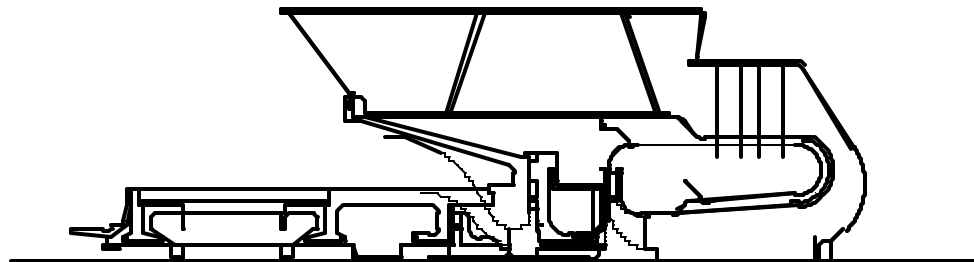
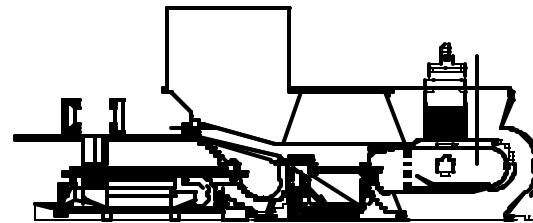


MicroTurbines & Fuel Cell Hybrid Power Systems (HPS)

30kW



60kW



200kW

April 17, 2002



MicroTurbines & Fuel Cell Hybrid Power Systems (HPS)

C-30 and C-60 Turbine Rotors



April 17, 2002



MicroTurbines & Fuel Cell Hybrid Power Systems (HPS)

HPS system considerations:

- Potential for highest thermal efficiency
 - Ultra low emissions
 - Cost trends (\$/kW)
 - Fuel cells
 - Microturbines
 - Power electronics
- [All seem to be going in right direction]

MicroTurbines & Fuel Cell Hybrid Power Systems (HPS)

Another HPS view:

- Considered microturbine fuel cell HPS
 - Power range: ~40kW up to ~600kW
 - Fuel cell types: PEM, MC, & SO
- General observations
 - Highest electrical efficiency (~60%)
 - Pressurized high temperature fuel cell
 - Unfired microturbine @ ~20% HPS output
 - Lowest capital cost (\$/kW)
 - Co-fired (combustor & FC)
 - Microturbine @ <50% HPS output
 - 40+% electrical efficiency @ full output
 - Excellent part load efficiency

MicroTurbines & Fuel Cell Hybrid Power Systems (HPS)

Small HPS (<1MW) with microturbines

- Potential near term deployment
- Modest R&D investment
- Exhaust heat available (CHP/BCHP)
- Electrical efficiency near 60%
- Ultra low emissions
- DER/DG applications
- Gain experience for larger HPS

